

NANOSECOND PULSE GENERATORS FOR MAGNETRON OPERATION

by

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ABSTRACT

To operate with pulse durations of under 15 ns, most magnetrons require a special type of modulation signal. This paper describes the design and operation of practical short pulse modulator circuits providing magnetron outputs of as short as 7 ns. The resulting transmitters provide an economical approach to high resolution radar systems. The short pulse techniques have also been used to enhance the coherent operation of magnetrons which are being pumped with an RF reference signal.

Introduction

For many radar applications where high resolution is required there is considerable appeal to the use of an inexpensive, conventional radar system with a magnetron transmitter operating with very short pulses. In addition to economy, such a system would have the advantage of providing minimum range coverage to within a few feet of the antenna. This feature is important in active seekers for missiles and in radar activated fuzes, since radar guidance or fuzing information can be provided almost to the point of impact. Also, a short pulse seeker is more nearly immune to some types of countermeasures.

A primary deterrent to the use of short pulse magnetron transmitters has been the fact that most magnetrons will not operate with short pulses unless special conditions are set up by the modulator to ensure that the tube goes into oscillation properly on each pulse. The problem has been recognized and understood for years, but little has been done until recently to develop practical modulators which satisfy the basic magnetron requirements for short pulse operation.

Magnetron Requirements for Short Pulse Operation

A typical pulse magnetron has a dynamic voltage-current characteristic as shown in Figure 1. As the pulse voltage rises toward the Hartree level (Reference 1) the space charge builds up around the cathode but no oscillations occur. At the Hartree voltage there is considerable noise energy in the magnetron caused by the motion of the electrons in the space charge. Noise, in the proper frequency region, supplies the energy from which oscillations start. The process is statistical in nature, and the time required for oscillations to start has some statistical distribution. The rising edge of the voltage pulse must permit a finite "dwell time" in the Hartree region to ensure that oscillations start properly in each pulse. If the voltage

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risers too rapidly through the Hartree region, the tube may oscillate in the wrong mode (and wrong frequency) or fail to oscillate at all. Some pulses may occur at the right frequency but at a reduced power level. In any case, there will be a large percentage of missing and degraded pulses.

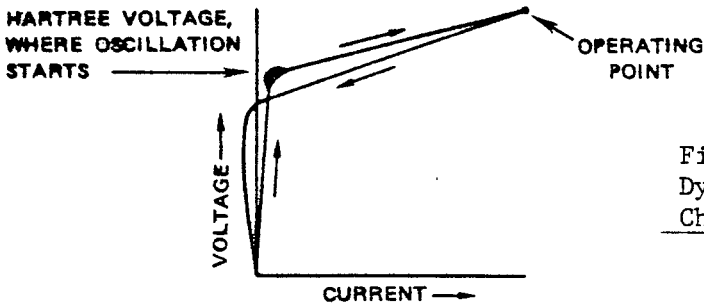


Figure 1. Typical Magnetron Dynamic Pulse Voltage-Current Characteristic.

The problem of operating a magnetron with short pulses creates conflicting requirements. The short pulse must, of necessity, have a short rise time and fall time. The short rise time conflicts with the requirement that a certain dwell time must be spent in the Hartree region. The result is that for any magnetron there is a certain minimum pulse duration at which the tube may be operated by conventional pulsing methods.

Through the use of appropriate modulator techniques, it is possible to operate magnetrons with pulses as short as 10 ns. To accomplish this, a relatively long pulse, or pedestal, is applied to the magnetron driving it up to, but not beyond, the Hartree voltage. A long dwell time is provided in the Hartree region which gives the tube every opportunity to go into oscillation in the proper mode, but at extremely low power. A short pulse is then superimposed on the pedestal pulse and drives the tube to its full output level. Since oscillations have already started at the time the short pulse occurs, there are no start-up problems. Typical voltage and current pulses are shown in Figure 2.

For most magnetrons, the pedestal voltage rate of rise is not critical and the waveform may be nearly sinusoidal in appearance. Some magnetrons, however, have a specified minimum value for voltage rate of rise, and the pedestal must be more nearly rectangular in shape.

Some Basic Designs for Pedestal and Short Pulse Generators

It is desirable to have a certain amount of individual control over both the pedestal pulse and the short pulse amplitudes. Therefore, it is convenient to generate these pulses separately and then combine them. Probably the simplest and most practical approach is to use two separate, line-type modulators as shown in Figure 2. The energy for the pedestal pulse is stored in C_1 which has been charged to a voltage of $2E$ by DC resonance charging. When S_1 is triggered, C_1 discharges in the series path through S_1 , L_2 , and the primary of pulse transformer T_1 . The resulting cyclical voltage is stepped-up on the secondary of T_1 and applied to the magnetron cathode. The first cycle

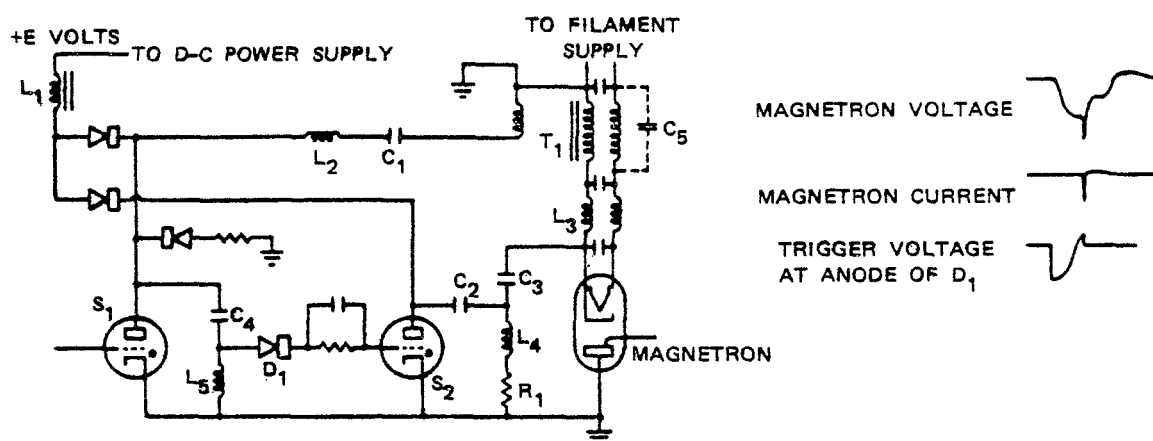


Figure 2. Typical Schematic and Waveforms for Transmitter With Short Pulse Superimposed on a Pedestal.

of this oscillatory voltage is the pedestal pulse. The peak of the pedestal occurs after one-half cycle, and at this time C_3 is charged up to the full pedestal voltage. Energy has been transferred from C_1 to $C_3 + C_s$, where C_s is the stray capacity across the secondary. Neglecting losses the voltage on C_3 after one-half cycle is given by

$$E_{C_3} = \frac{\frac{4E}{r(C_3 + C_s)}}{\frac{C_1}{C_1} + 1} \quad \text{Eq. 1}$$

where r = step-up ratio of T_1 . If $C_1 = r^2(C_3 + C_S)$ the energy transfer is complete, and $E_{C_3} = 2Er$, while no charge remains on C_1 .

The energy for the short pulse is stored in capacitor C_2 , which has been charged to a voltage of $2E$ by DC resonance charging in the same manner as C_1 . Assume that S_2 switches into conduction as the pedestal voltage reaches its peak value. The main discharge path for C_2 is through S_2 and through C_3 in series with the magnetron, whose cathode is lifted from the pedestal voltage to the full short pulse voltage. The short pulse is isolated from the pedestal pulse circuitry by L_3 , which has a high reactance to the short pulse but negligible reactance to the pedestal. L_4 and R_1 in series also have fairly high impedance to the short pulse but very low impedance to the pedestal.

The trigger for S_2 , the short pulse switch, could be generated by any means desired. However, a high voltage trigger with proper timing may be conveniently generated using circuitry as shown in Figure 2. The energy for the trigger is stored on C_4 , which is charged up to $2E$ along with C_1 and C_2 . When S_1 conducts, the upper side of C_4 drops to ground potential while the lower side drops to a voltage of nearly $-2E$. This large, negative voltage is blocked from the grid of S_2 by diode D_1 . C_4 discharges through L_5 giving the start of an oscillatory waveform on L_5 . The large, negative pulse at L_5 is followed by a positive backswing

which is coupled onto the grid of S_2 causing it to trigger. The timing of this trigger can be controlled by adjusting the values of C_4 and L_5 .

The primary factors influencing the duration of the short pulse are the values of C_2 and C_3 , the magnitude of the distributed inductance in the discharge path of C_2 , and the switching time of S_2 . The latter set the lower limit on pulse duration which can be achieved. Experience has shown this to be on the order of 7 ns using a Ku/71 hydrogen thyratron. Since the short pulse is coupled directly onto the magnetron without the use of a pulse transformer, the distributed inductance can be kept very low.

The circuit of Figure 2 can be made very flexible for use with a variety of magnetrons by using a separate DC supply for the short pulse generator. In this way the pedestal and the short pulse voltages can be made independently adjustable over a wide range. For minimum duration of the short pulse, S_2 should be a hydrogen thyratron. However, the pedestal switch, S_1 , can often consist of a solid-state device plus a saturating inductor or a combination of devices such as silicon controlled rectifiers or reverse switching rectifiers.

An adaptation of the circuit of Figure 2 has been used in a dual mode transmitter having two selectable pulse widths, 400 ns for a long range search mode and 10 ns for a short range, high resolution mode. A simplified schematic is shown in Figure 3. A radar system employing this transmitter, plus an appropriate receiver, was used as a beach surveillance radar in landing exercises carried on by the U.S. Navy (Reference 2). A time-compressed display system was used in conjunction with the radar in attempts to detect swimmers coming ashore through surf. The swimmers were detected and intercepted in all cases.

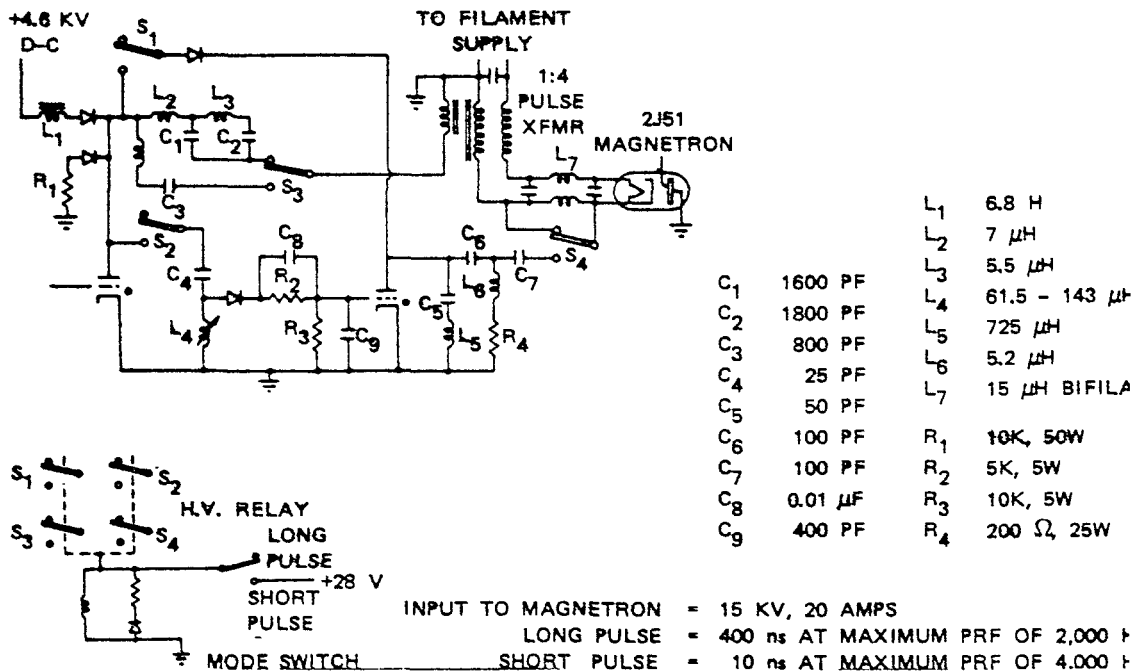


Figure 3. Dual Mode Transmitter.

Figure 4 shows a comparison of radar resolution on a PPI scope of a 50-ns pulse versus a 10-ns pulse.

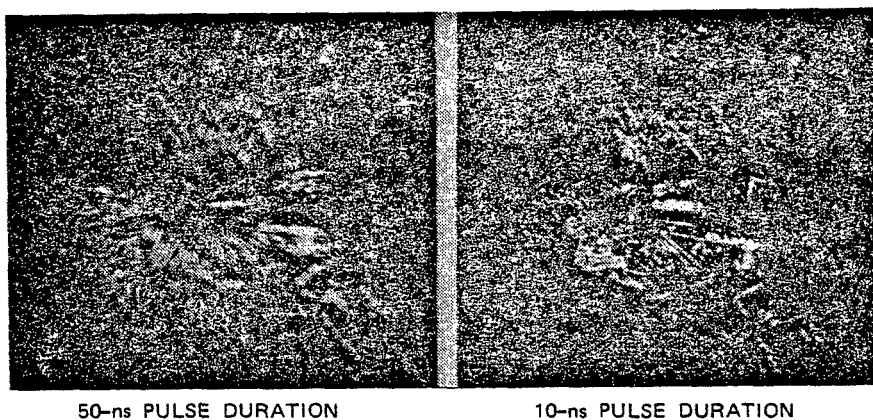


Figure 4. Photographs of PPI Scope. (Maximum range is approximately one-fourth mile. Background clutter consists primarily of sagebrush with individual plants resolved on right.)

Magnetron Coherence Using a Short Pulse Modulator

Since a magnetron starts to oscillate from self-generated noise, the RF output has a random phase relationship from pulse to pulse. However, if a CW or pulsed CW reference signal of proper frequency is injected into the magnetron (injection priming), it is possible to force the oscillations to start in the same phase on each pulse (Reference 3). The magnetron is then operating coherently with the reference signal and could be used in a coherent radar system. Using an X-band magnetron such as the Microwave Associates MA-249B, pulse modulated in the normal manner, it is possible to retain coherence over a 10-MHz magnetron tuning range with an output-to-injection ratio of 40 dB.

The effectiveness of injection priming can be considerably improved through the use of a pulse superimposed on a pedestal. The priming signal is injected during the pedestal pulse, whose peak voltage in this case is just below the Hartree level. This provides a relatively long period of time in which the priming signal can exert its influence in causing oscillations to start. Again, using an MA-249B magnetron and an output-to-injection ratio of 40 dB, the bandwidth over which coherence can be maintained is extended to over 200 MHz. To determine the quality of coherence, a study was made of the spectral purity of the magnetron output over a magnetron tuning bandwidth of 100 MHz (Reference 4). Noise measured in a 1-Hz band, 100 Hz from the carrier, was down by over 50 dB in all cases, for an output-to-injection ratio of 30 dB. More complete data are shown in Figure 5.

Higher coherent power levels may be achieved by cascading two or more pulsed magnetrons. The RF reference signal is injected into a low power magnetron, whose output is injected into a magnetron of higher power, etc. A device of this type has been built using three X-band magnetrons, each pulsed with a pedestal with a short pulse superimposed.

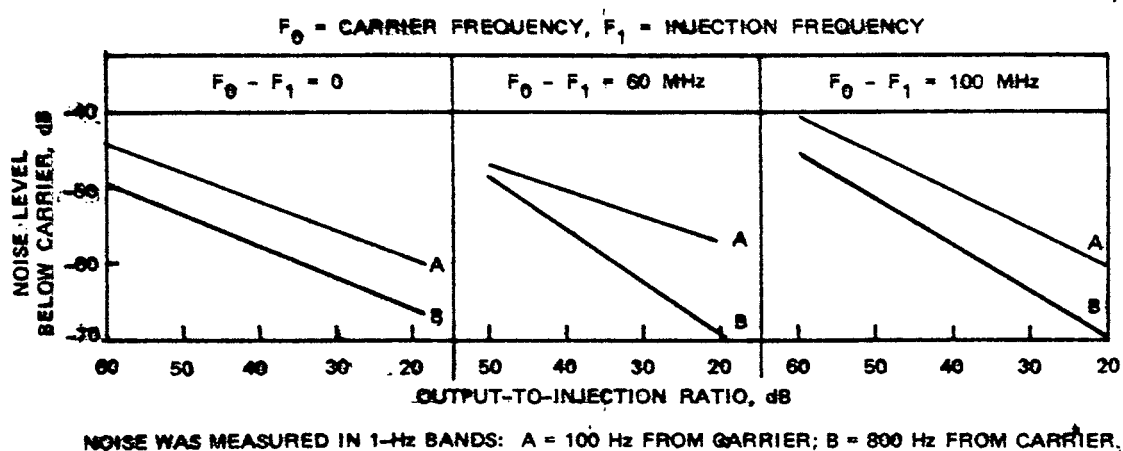


Figure 5. Magnetron Noise Versus Output-to-Injection Ratio (adapted from Reference 4).

The reference signal was 40 mW and the output of the final magnetron was 36 kW, an overall gain of nearly 60 dB. Spectral purity measurements have not been made; however, initial tests indicate that noise is still at least 50 dB below the peak carrier level for an overall output-to-injection ratio of 60 dB.

Conclusions

A unique design approach has been described for pulse modulators which enable magnetrons to operate with much shorter pulses than would be possible with conventional pulsing. Short pulse transmitters of this type have been built to meet the requirements of several high resolution radar systems. Such systems are considerably more economical than those using pulse compression. The short pulse technique improves the operation of a magnetron in coherence with a reference signal when used in conjunction with injection priming.

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